Single-spin azimuthal asymmetry in exclusive electroproduction of π^+ mesons on transversely polarized protons

The HERMES Collaboration

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The measurement presented here aims at exploring generalized parton distributions (GPDs), parameterizations of the nucleon structure that offer the possibility of constructing a three-dimensional picture of the nucleon. The interest in GPDs does not only stem from their ability of providing a three-dimensional picture of the nucleon, but also from an important relation that can be used to determine the total angular momentum of the partons.

Presently, much of our knowledge of the quark-gluon structure of the nucleon comes from scattering lepton beams off nucleon targets. Such interactions are described by the exchange of a virtual photon γ^* between a beam lepton and a target nucleon (as shown in the top left corner of the diagram in Fig. 1). The virtuality Q^2 of the photon exchanged sets the scale for whether the nucleon is probed as a whole or as an ensemble of interacting partons.

This leads to various kinds of experiments that provide information on the nucleon structure. In elastic scattering, where the nucleon stays intact, form factors describe the ”electro-magnetic size” of the nucleon, e.g., its charge radius. In deep-inelastic scattering the nucleon breaks up and many hadronic particles are produced. From such measurements, parton distributions can be deduced, which provide the information on the momentum distribution of the partons in the nucleon. More recently, a new type of experiments has emerged: hard exclusive scattering. In that case, the large values of Q^2 allows one to probe the partonic structure of the nucleon, just as in deep-inelastic scattering. Furthermore, requiring the nucleon to stay intact results in additional information about the spatial distribution of the partons. However, in order for the proton to be able to absorb a photon with large Q^2 without breaking up, at least one more final-state particle needs to be produced. Selection of a particular final state gives particular information about the nucleon structure, i.e., particular combinations of GPDs.

For the present analysis, we are interested in the hard exclusive reaction $ep^\uparrow \rightarrow en\pi^+$ with transversely polarized protons. Here ’transversely’ means that the spins of the protons are oriented perpendicular to the direction of the incoming electron. Figure 1 shows a pictorial diagram for this reaction, in which a π^+ is produced.

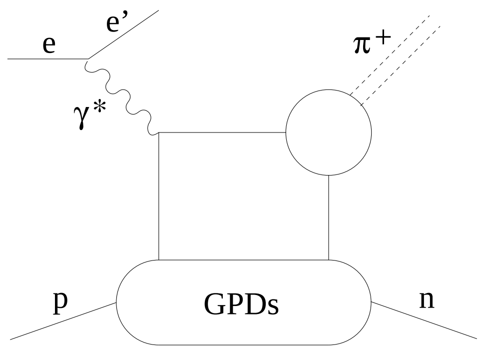

FIG. 1: Diagram for the hard exclusive process $ep \rightarrow en\pi^+$.

The probability for such a reaction without a preferred proton-spin direction, i.e., the spin-averaged cross section, is sensitive to certain combinations of GPDs. It was measured previously at HERMES. The transverse-spin-dependent cross section is also of interest because it is sensitive to entirely different combinations of GPDs. The spin-dependent cross section is asymmetric in the azimuthal distribution of the produced pions about the virtual-photon direction. The relevant azimuthal angles describing the event topology are denoted as ϕ and ϕ_S. The spin-dependent cross section for the above reaction can be Fourier expanded in terms of six $\sin\Phi$ modulations and their corresponding amplitudes $A_{\rm UT}^{\sin\Phi}$. Here Φ represents different linear combinations of ϕ and ϕ_S.

The 27 GeV leptons provided by HERA at DESY are scattered off a transversely polarized gas target. In order to extract our observables, the six Fourier amplitudes, we performed a fit to the measured yield of events of interest. In Fig. 2 (left), the $\sin(\phi-\phi_S)$ Fourier amplitude is presented as a function of the momentum transfer t' to the target. The data are compared to calculations based on GPD models based on different hypotheses. The main contribution to this amplitude is expected to come from GPDs that conserve the spin of the quark interacting with the virtual photon. The solid line represents a calculation in which the GPDs are parameterized using a simple model called the pion pole. Our data clearly disagree with the large value that was predicted for this amplitude. The variants of the GPD models represented by the dashed, dotted, and dash-dotted lines include other contributions instead of or in addition to the pion pole.

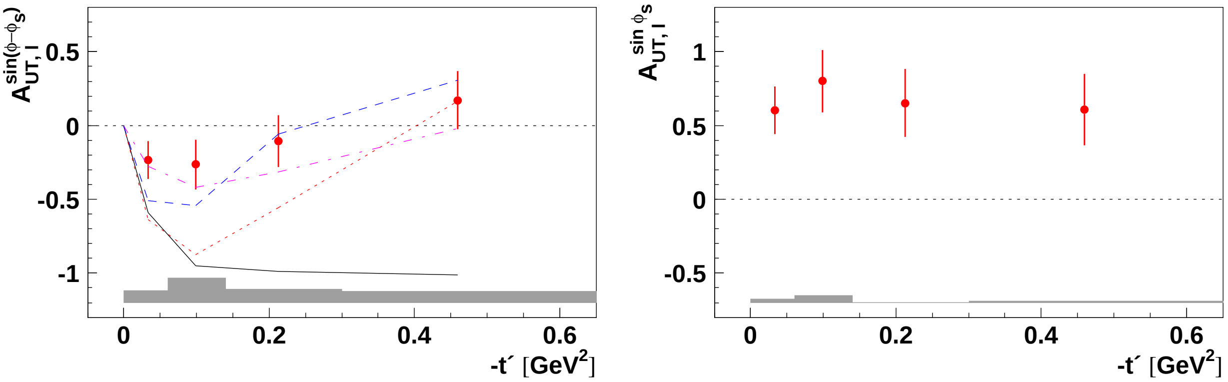

FIG. 2: The Fourier amplitude for the $\sin(\phi-\phi_S)$ (left) and the $\sin\phi_S$ (right) azimuthal modulations of the proton-spin-dependent cross section.

All the other Fourier amplitudes are expected to be suppressed by at least one power of $1/Q$. This is one of the reasons that no theoretical predictions for them were made prior to our results. On the other hand, such measurements are possible only at moderate values of Q^2, such as accessible at HERMES. Our measurement reveals that these amplitudes are compatible with zero, except for the amplitude $A_{\rm UT}^{\sin\phi_S}$, shown in Fig. 2 (right). This $\sin\phi_S$ amplitudes is found to be surprisingly large. In order to describe the data by GPD models, a contribution from a GPD is required that was previously expected to be suppressed and therefore neglected in model calculations. This GPD is related to the alteration of the spin of the quark as a result of its interaction with the virtual photon.

In conclusion, this first measurement of the azimuthal asymmetry with transversely polarized protons, the past HERMES measurements of the cross section and the azimuthal asymmetry using longitudinally polarized protons, together comprise a first useful set of results for the study of exclusive pion electroproduction and for obtaining information about generalized parton distributions.